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GAS HYDRATE ACCUMULATIONS AT THE ALASKA NORTH SLOPE: TOTAL ASSESSMENT BASED ON 3D PETROLEUM SYSTEM MODELING

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ABSTRACT

The Alaska North Slope comprises an area of about 400,000 km^2 including prominent gas and oil fields. Gas hydrates occur widely at the Alaska North Slope. A recent assessment by the USGS estimates 0.7-4.47 x 10^{12} m^3 of technically recoverable gas hydrates based on well data and drilled hydrate accumulations. In spring 2012 a production field trial, testing CO2/N2 injection and depressurization, was conducted by USDOE/JOGMEC/ConocoPhillips at the Ignik Sikumi site. The 3D geological model of the Alaska North Slope developed by the USGS and Schlumberger is used to test the new gas hydrate module in the petroleum systems modeling software PetroMod®. Model results of the present extent of the gas hydrate stability zone (GHSZ) are in good agreement with results from well data. The model simulations reveal that the evolution of the GHSZ over time is primarily controlled by the climatic conditions regulating the extent of the permafrost during the last 1 Myr. Preliminary model runs predict the highest gas hydrate saturations near the major faults and at the bottom of the GHSZ, where thermogenic methane gas accumulates after migration through the most permeable stratigraphic layers (e.g. Sag River Sandstone Fm, Ivishak Fm). Gas hydrate saturations predicted for the Mount Elbert Stratigraphic Test Well and the Ignik Sikumi sites are basically controlled by the alternation of layers with different permeability and the fault properties (time of opening, permeability, etc). Further results including a total gas hydrate assessment for the Alaska North Slope will be presented during the conference.

Keywords: gas hydrates, Alaska North Slope, fault, saturation, total volume.

NOMENCLATURE

Fm Formation
GHSZ Gas Hydrate Stability Zone
HI Hydrogen Index
TOC Total Organic Carbon

INTRODUCTION

A petroleum system modeling simulates the generation, migration and accumulation of petroleum components, classically gas and oil. Since 2011, PetroMod® incorporates methane hydrate as a modeled component, which is fully simulated including: 1) the routines for the physical and thermodynamic properties of gas hydrates; 2) the kinetic formulation for the formation and dissociation of gas hydrates; 3) the kinetic formulation for biogenic methane generation at low temperature; and 4) improved

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numeric higher temporal and spatial resolution (Fig. 1, [1]). This new tool enables the prediction of methane hydrate accumulations in 3D at the basin scale.

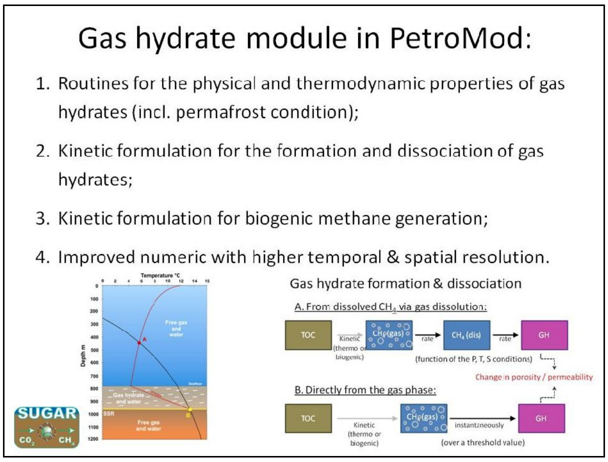

Figure 1. Improvements included in the new Gas Hydrate module of PetroMod®.

Geological Setting

The Alaska North Slope extends for about 1000 x 400 km in the Northeastern edge of America (Fig. 2). Geologically, the margin evolved from a passive margin, to a rift and posterior foreland basin followed by a thrust belt [2, 3]. The antiformal feature known as the Barrow Arch runs in East-to-West direction in the northern part of the province.

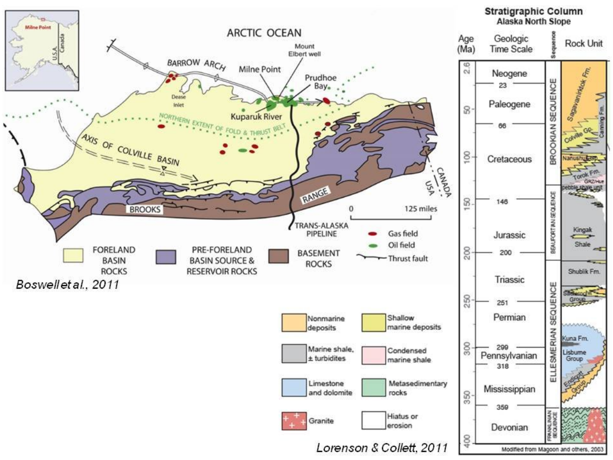

Figure 2. Geological map and stratigraphic column of the Alaska North Slope [2, 7].

The stratigraphy of the Alaska North Slope is composed of four major sequences, from which the Saganavirktok Fm (Brookian Sequence) is the primary reservoir for gas hydrate [4]. Petroleum originates at four main source rocks, comprising the Shublik Fm, the Kingak shale, a shale unit, and the Hue Shale Fm [3]. Organic geochemistry data indicates that posterior biodegradation of the petroleum occurs, generating methane [4]. The main stratigraphic migration pathways identified in the region include the relatively high permeability Sag River sandstones, which ultimately allow the migration of gas up to the top of the anticline structure [4].

Gas hydrates were firstly discovered in the Alaska North Slope in 1993 [5, 6]. Hydrates have been so far detected or inferred in ~50 exploratory and production wells [4]. Based on these data, the USGS estimates in 0.7-4.47 x 10^{12} m^3 the technically recoverable gas hydrates [7]. In spring 2012 a production field trial, testing CO2/N2 injection and depressurization, was conducted by USDOE/JOGMEC/ConocoPhillips at the Ignik Sikumi site (e.g. [8]).

MODEL DESCRIPTION

For this study, we used the Alaska North Slope model developed by Schlumberger and the USGS, at a grid spacing of 1x1 km [9]. The model simulates the deposition of 43 sedimentary layers with a number of progradational units corresponding to the Brookian sequence (Fig. 2). The age model is based on previously published regional studies [9].

The distribution of lithologies for each layer is described by a distribution map, as well as the initial TOC (total organic carbon) content. TOC content as well as HI (hydrogen index) data are based on Peters et al. [3].

The heat flow was calibrated in PetroMod® with vitrinite reflectance data measured on well samples. Surface temperature and paleo-water depth maps are based on previous paleotectonic studies (e.g. [3]). In order to mimic the low present-day surface temperatures, a 0 ºC isotherm map was imposed into the base of the actual permafrost, based on well data.

RESULTS AND DISCUSSION

The model results predict a gas hydrate stability zone thickness of up to 1100 m, including both cells under permafrost conditions and above 0 ºC. This result is in good accordance to a previously published map by Collett et al. [5], based on well data measurements. Low surface temperatures

extended in the Alaska North Slope during the last 1 Myr, controlling the growth of the permafrost in the region. Under these conditions, the GHSZ increased gradually until its present extension, due to the presence of ice in the sediment pore space.
The preliminary model-runs show that most methane generation occurs in the Kingak, Shublik and Hue-Jago formations at the Colville trough at 3000-5000 mbsl (Fig. 2). A major portion of the gas migrates directly up from the southern flank of the Barrow arch in the Foothills region. Although several thrust-faults are included in the southern part of the model, they do not act as favorable migration pathways, and migration there is relatively dispersed (Fig. 3).

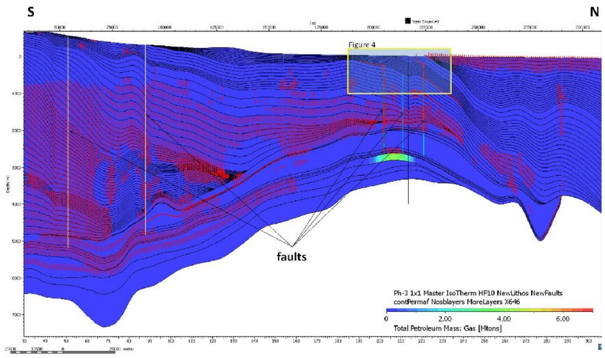

Figure 3. N - S section showing the Petroleum Mass (oil and gas, no gas hydrates) left in the model. Red arrows represent gas migration pathways. The main faults included in the model are shown as vertical lines.

Another portion of the generated thermogenic methane at depth migrates up along the relatively permeable sedimentary layers, mainly the Sag River sequence, accumulating at the top of the anticline (Fig. 3). From there, gas migrates further up crossing the sedimentary strata and following the main faults occurring in the area (Fig. 3). Methane is finally distributed along the most permeable layers of the shallower Brookian sediments, and gas hydrates accumulate preferentially in the cells at the bottom of the GHSZ (Fig. 4).

CONCLUSIONS

The application of the new “Gas Hydrate” module of PetroMod® in the Alaska North Slope area shows that gas hydrates have been stable in the onshore region during the last million of years, mainly controlled by the low temperatures and the extension of the permafrost conditions.

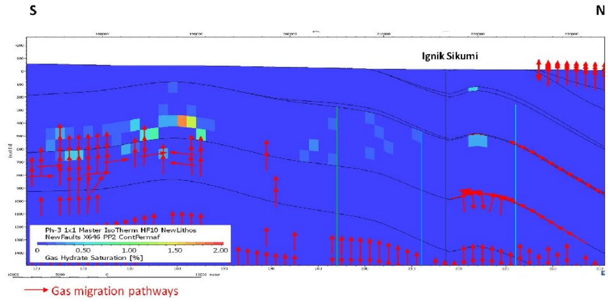

Figure 4. Detail of the volume of pore space saturated with gas hydrates in the vicinity of the Ignik Sikumi field test in the Alaska North Slope.

Hydrocarbon migration in the sedimentary column is controlled by the defined horizontal and vertical permeability. Open faults act as additional preferential pathways for gas migration, and result crucial in thick sedimentary sequences such as in the Alaska North Slope.
New results, including the comparison of calculated gas hydrate saturations with measured data at Ignik Sikumi and Mount Elbert test well will be presented during the conference. We will discuss the effect of the fault properties in the estimated total gas hydrate budget, as well.

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